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DRAWINGS ATTACHED

1313412

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(54) ELECTROPHORETIC IMAGE REPRODUCTION DEVICE

(71) We, MATSUSHITA ELECTRIC INDUSTRIAL COMPANY LIMITED, a Japanese company, of 1006 Oaza Kadoma, Osaka-fu, Kadoma-shi, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

10 This invention relates to a display and/or recording device and particularly to an electrophoretic display and/or recording device comprising at least one finely divided electrophoretic material, suspended in a suspension medium.

15 A cathode ray tube is now widely used as electric display apparatus because of its high speed of operation, the ease with which it can be scanned, and so on, but it still has some disadvantages. For example, it is difficult to produce a cathode ray tube in the form of a flat panel or of very large size. In addition, it requires a high voltage for its operation.

25 There have been proposed many electric panel display apparatuses such as electroluminescent panels, arrays of luminescent diodes, incandescent lamps or plasma cells. These are all self-luminescent devices, but are not in widespread use because of their inferiority in, for example, luminescent efficiency, life or cost, as compared with the cathode-ray tube. Further, it is difficult for such devices to memorize or record the displayed image. Liquid crystals have been suggested as possible media with which to construct a flat panel display apparatus capable of changing colour by a change in an electric field or change

in temperature. At present such devices are not actually in practical use because their properties are not entirely satisfactory for display purposes.

The phenomenon of electrophoresis is widely used in the electro-deposition of fine particles and in development of electrostatic latent images in electrophotography. Patent specifications Nos. 1,124,625 and 1,124,626 and also U.S. Patents 3,145,156 and 2,940,847 describe methods of producing images by utilizing electrophoresis or photo-electrophoresis.

According to these prior art methods, charged particles in the suspension medium are transported to the surface of an electrode or a sheet so as to reproduce a pattern corresponding to that of an initial electric field or initial light image. The visible image can be obtained by removing the electrode or the sheet.

The known devices have not aimed at producing a variation in the optical reflective property of a suspension itself by a change in the spatial distribution of electrophoretic particles in the suspension. In other words, the prior art relates essentially to the reproduction of permanent visible images but not to a variable display system.

According to the present invention there is provided an image display or recording device comprising an electrophoretic suspension layer comprising at least one material which exhibits electrophoresis even in the absence of illumination suspended in a suspension medium, first and second bounding members immediately adjacent the main surfaces of said layer and comprising first and second

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electrode means respectively, at least one of the members being transparent and the first and second electrode means being arranged to produce in said layer an electric field such as to cause a said electrophoretic material to be deposited upon one of the bounding members.

An improved method of producing a pattern of high contrast by using electrophoretic suspension layers in a manner similar to that used in the present invention is described and claimed in co-pending patent application No. 19612/70 (Serial No. 1313413).

Preferred features and advantages of the present invention will become apparent from the following description of embodiments thereof taken in conjunction with the accompanying drawings, in the several Figures of which corresponding elements are denoted by like reference numerals.

In the drawings:

Figures 1a and 1b are cross-sectional views of one embodiment of a display and/or recording panel;

Figures 2a and 2b are cross-sectional views of another embodiment of display and/or recording panel;

Figures 3a and 3b are cross-sectional views of still another embodiment;

Figures 4a and 4b are cross-sectional views of a further embodiment;

Figure 5 is a schematic perspective view, partially broken away, of a pattern display panel;

Figure 6a is a front view of an electrode suitable for use in a character display panel;

Figure 6b is a cross-sectional view of the panel of Figure 6a;

Figure 6c is a front view of another electrode suitable for use in a character display panel;

Figure 7 is a schematic perspective view, partially broken away, of an image display panel;

Figures 8a, 8b and 8c are schematic cross-sectional views of an electrostatic image display and/or recording panel;

Figure 9 is a cross-sectional view of an image display device;

Figure 10 is a schematic cross-sectional view of an electrostatic image display and/or recording panel;

Figure 11 is a cross-sectional view of a display panel;

Figures 12a and 12b are cross-sectional views of a display panel;

Figure 12c is a schematic front view of a display panel; and

Figure 13 is a schematic perspective view of a sheet with holes for use in the panel of Figure 12.

The size and shapes of many elements of the drawings have been purposely distorted in size or shape in order to more fully and clearly describe the invention.

Referring to Figure 1a, reference numeral 1 designates, generally, a display and/or recording panel which includes an electrophoretic suspension layer 2.

When suspension layer 2 is in a fluid state, it is enclosed in a housing 3 consisting of a frame 38 and two opposed major housing walls 4 and 5, which are transparent.

Suspension layer 2 has two opposed major surfaces juxtaposed to the opposed major housing walls 4 and 5 and includes a dispersion of at least one finely divided electrophoretic substance 6 suspended in a suspension medium 7. For clarity of illustration the particles of the substance 6 are shown greatly enlarged in this and subsequent Figures. In contact, respectively, with the opposed major surfaces of suspension layer 2 are a first electrode 8 and a second electrode 9 which are transparent and which are attached to the inner surfaces of the housing walls 4 and 5.

The electrodes 8 and 9 are connected to output terminals of a direct voltage source 10 through a polarity-reversing switching device 11. Before an electric field is supplied to suspension layer 2 from source 10, the electrophoretic substance 6, in finely divided powder form, is distributed uniformly throughout the suspension medium 7 as shown in Figure 1a. If, for example the electrophoretic substance 6 is white and the suspension medium 7 is black, the suspension layer 2 appears grey when illuminated by an incandescent lamp. When the grey suspension layer 2 is subjected to a unidirectional electric field resulting from a direct voltage applied to electrodes 8, 9, the electrophoretic substance 6 is caused to move electrophoretically in the direction either of the cathode or of the anode, depending upon the polarity of its charge. For example, if the material 6 acquires a negative charge, it migrates towards and is deposited on the anode 8 and thus has a spatial distribution different from the initial uniform distribution, shown in Figure 1b.

The resultant suspension layer 2 has a different spatial distribution of the substance 6 and different optical reflectance properties from those of the original suspension layer 2 having a uniform distribution of the material 6. Specifically, the display and/or recording panel 1 will thus appear white on the anode side and black on the cathode side.

The colour characteristic of the display and/or recording panel 1 may be reversed by reversing the polarity of the voltage applied to the panel. When the amount of the electrophoretic substance deposited on the anode is insufficient to conceal the resultant suspension, the panel has on the anode side a half-tone appearance dependent upon the covering power of the electrophoretic substance which is deposited on the anode. By the "covering power" of the suspension layer is meant the degree to which the suspension layer deposited

on a base substance hides it. Therefore, the colour characteristic at the anode side can be continuously controlled by controlling the amount of the electrophoretic substance deposited on the electrode. The amount of the electrophoretic substance deposited on the electrode can be controlled by varying the strength or the length of time of application of a direct voltage. The colour characteristic at the cathode side also is changed by the electrophoretic migration of the electrophoretic material to the anode. In this manner the display and/or recording panel 1 can have its colour characteristic changed by varying the strength or the polarity of an applied electric field or the length of time during which it is applied.

Electrophoretic substances deposited on an electrode surface by electrophoresis will remain on the electrode even after removal of the applied electric field. This means that display device according to the present invention employing electrophoretic migration of an electrophoretic substance suspended in a suspension medium can store output information without using further electric power. The panel can have its original colour characteristic restored by applying an appropriate unidirectional electric field having a direction opposite to that of the initial unidirectional electric field or by applying strong mechanical vibrations to the device. Application of an alternating electric field to the suspension layer can effectively restore the original colour characteristic of the panel.

The suspension medium 7 can be prepared so as to have a desired colour by dissolving a coloured substance, such as a dye, in a colourless liquid or by suspending electrically neutral coloured particles, such as dyes or pigments in a colourless liquid. For example, a suspension medium which is deep blue in colour can be prepared by dissolving oil black dye in ethyl acetate or in kerosene.

A violet, brown or green coloured suspension medium can be prepared by dissolving cobalt naphthionate, manganese naphthionate or nickel naphthionate respectively in trichlorotrifluoroethane.

In Figure 2a a coloured porous layer 12 is shown to be immersed in a colourless suspension medium 13. In the device of Figure 2a, a colour which is a mixture of the colours of the electrophoretic substance 6 and of the coloured porous layer 12 can initially be seen from both electrodes.

When a unidirectional electric field is produced between electrodes 8 and 9, the particles of electrophoretic material 6 are caused to pass through the coloured porous layer 12 and to be deposited upon one electrode or the other depending upon the polarity of their charge, for example upon the anode, as shown in Figure 2b. When the layer of the electrophoretic material 6 deposited on the anode

has enough covering power, the device of Figure 2b has on the anode side the same colour as the electrophoretic substance 6. When the coloured porous layer 12 can also conceal the layer of electrophoretic substance 6 deposited on the anode, the device of Figure 2b has, on the cathode side, almost the same colour as the coloured porous layer 12.

The colour characteristic can be reversed by reversing the polarity of the applied potential. It is also possible to use an electrophoretic suspension layer including a coloured porous layer immersed in a coloured suspension medium and having at least one electrophoretic substance suspended therein. The coloured porous layer can be made from any sheet material having suitably sized pores therein. The size of the pores must be large enough to permit the particles of electrophoretic substance to pass therethrough and small enough to conceal the electrophoretic substance. Suitable materials are a cloth or a mesh woven of natural or artificial fibres; a fibrous sheet having thousands of irregular pores; a thin plate pierced by multitudinous tiny holes; or a sheet formed of granular material so bound together with resin or other adhesive agent as to include a large number of pores.

In Figure 3a a suspension medium 15, which may be either coloured or colourless, includes at least two different electrophoretic substances 16 and 17 each in a finely divided powder form. The suspension medium 15 and the substances 16 and 17 together comprise the electrophoretic suspension layer 18. The two electrophoretic substances 16 and 17 differ from each other both in charge polarity and in their optical reflectance properties.

In its inactive condition the device of Figure 3a displays at its opposite sides a colour which is a mixture of the colours of those of the two kinds of electrophoretic substances 16 and 17, and the colour of the suspension medium 15.

When a unidirectional electric field is produced in the electrophoretic suspension layer 18, the two electrophoretic substances 16 and 17 are caused to move electrophoretically in opposite directions. One substance, that with a positive polarity, moves toward and is deposited on the cathode and the other substance, that with a negative polarity, moves toward and is deposited on the anode, as shown in Figure 3b. If, for example, the electrophoretic substance 16 with positive charge polarity is yellow, and the electrophoretic substance 17 with negative polarity is cyan, and before the device is subjected to the unidirectional electric field, the device will, if the suspension medium is colourless show a green colour at both electrodes due to the uniform spatial distribution of the yellow substance 16 and the cyan substance 17, as shown in Figure 3a. When a spatial distribution of electrophoretic substances 16 and 17 which is shown in Figure

3b is produced the cathode side of the device will appear yellow and the anode side will appear cyan.

The colour characteristic of the display and/or recording device can be reversed by reversing the polarity of the applied voltage.

In the embodiment shown in Figure 4a an electrophoretic suspension layer 21 comprises a suspension medium 15 which may be either coloured or colourless containing at least two different electrophoretic substances 19 and 20 in finely divided powder form. In this case the electrophoretic substances 19 and 20 have the same charge polarity but differ in their electrophoretic mobilities and optical reflectance properties. The device of Figure 4a initially has, at both sides, a colour which is a mixture of the colours of the two electrophoretic substances 19 and 20 and the colour of the suspension medium 15. When the two electrophoretic substances 19 and 20 are, for example, white and black, respectively, and the suspension medium 15 is colourless, the device initially appears grey at both sides. When a unidirectional electric field is applied to the suspension layer 21, the two electrophoretic materials 19 and 20 are caused to migrate electrophoretically in the same direction, but at different speeds.

When the electrophoretic substances 19 and 20 are positively charged and the electrophoretic mobility of 19 is greater than that of 20, the substance 19 moves faster in the suspension layer 21 under the effect of a unidirectional electric field than does the substance 20. As is shown in Figure 4b, the amount of the former substance deposited upon the cathode is greater than the amount of the latter substance. Therefore, the cathode side of the device appears whiter and the anode side blacker than before a unidirectional field was applied to the device.

The colouring of the display and/or recording device can be reversed by reversing the polarity of the applied voltage. As is apparent from the foregoing description and Figures, the colour of the suspension layer in the device can be changed in accordance with the invention. This is because the spatial distribution of electrophoretic material in the suspension is changed by the application of an electric field and a layer of at least one electrophoretic substance deposited on an electrode conceals or is concealed by another coloured component of the suspension, such as a coloured suspension medium, a coloured porous layer or another electrophoretic substance.

In the devices described in relation to the foregoing Figures, it is not always necessary that both of the two opposite major housing walls and both of the electrodes shall be transparent. It is possible to construct a display and/or recording device which shows a change in colour at one side only by employing one transparent housing wall and one

transparent electrode corresponding to that wall.

The device shown in Figure 5 includes a suspension layer 22 which may be any suitable electrophoretic suspension layer, such as the suspension layer 2, 14, 18 or 21 described in relation to Figures 1a, 2a, 3a or 4a. The suspension layer 22 includes at least one electrophoretic material suspended in a suspension medium and is enclosed in a housing 3 having two opposed major housing walls 4 and 5, at least one of which is transparent. In Figure 5, housing wall 4 is transparent. The first electrode 23 forms a pattern, which may be the E-shaped pattern shown. The second electrode 24 is transparent and extends uniformly across the whole of the transparent housing wall 4.

When a direct voltage from a source 10 is applied between the first electrode 23 and the second electrode 24 by way of switch 11 in a manner similar to that described above, the E-shaped or other pattern of the first electrode is displayed on the transparent electrode 24 due to electrophoretic migration of the electrophoretic material. A change in the polarity of the applied voltage results in a change in the colour of the displayed pattern.

The device shown in Figures 6a and 6b includes an electrophoretic suspension layer 22 which can be any suitable electrophoretic suspension layer, such as one of the suspension layers 2, 14, 18 or 21 described in relation to Figures 1a, 2a, 3a or 4a. The suspension layer 22 includes at least one electrophoretic material suspended in a suspension medium and is enclosed in a housing 3 having two opposed major housing walls 4 and 5.

A first electrode 25 is composed of a plurality of electrode portions S_1-S_n , which are isolated from each other. A second electrode 24 is transparent and extends uniformly across the whole of the transparent housing wall 4. The plurality of electrode portions S_1-S_n are connected by leads extending through housing wall 5 to electrical terminals T_1-T_n , positioned at the outer surface of said housing wall 5 as shown in Figure 6b. Different combinations of the plurality of segmental electrodes S_1-S_n may be excited to display a desired numerical character when a direct voltage is applied between the selected electrode portions of the first electrode and the second electrode 24. For example, a direct voltage applied between the second electrode 24 and the electrode portions $S_{11}, S_{12}, S_{13}, S_{14}$ and S_{15} of the first electrode will cause the device to display the numerical character 3.

An alternative method of connecting the plurality of electrode portions S_1-S_n to the terminals is shown in Figure 6c, where the electrode portions S_1-S_n are connected to electrical terminals positioned at the side surfaces of housing wall 5 by leads L_1-L_n .

formed on the same surface as that on which the electrode portions are positioned. These methods of connection are given as examples only and should not be taken as limitative.

5 The device shown in Figure 7 includes a suspension layer 22 which can be any of the electrophoretic suspension layers above described.

10 This suspension layer includes at least one electrophoretic material suspended in a suspension medium and is enclosed in a housing 3 having two spaced opposed major housing walls 4 and 5, at least one of which is transparent; in the drawing the housing wall 4 is shown as being transparent.

15 A first transparent electrode consists of a plurality of electrode strips x_1, x_2, x_3, \dots which are parallel to each other and which are attached to the inner surface of transparent housing wall 4. A second electrode is attached to the inner surface of housing wall 5 and consists of a plurality of electrode strips y_1, y_2, y_3, \dots which are parallel to each other and are orthogonal to electrode strips x_1, x_2, x_3, \dots .

20 A direct voltage is applied between a selected one of the electrode strips x_1, x_2, x_3, \dots and a selected one of the electrode strips y_1, y_2, y_3, \dots for example, between electrode strips x_2 and y_1 . The portion of the suspension layer 22 at the intersection of the two electrode strips x_2 and y_1 is then subjected to a unidirectional electric field and forms one picture element.

35 Narrower electrode strips can be used to form smaller picture elements.

40 The selection of more than one strip electrode from each of the sets of electrode strips forming the first and second electrodes will produce a desired pattern consisting of a plurality of picture elements. Scanning techniques known to the electrical display art can be utilized to scan the picture elements defined by the strips sequentially and cyclically.

45 The above described electrodes having parts arranged in a given pattern or formed of a plurality of electrode portions or electrode strips, as shown in Figures 5, 6 and 7, can be easily prepared by using any suitable known method such as electrodeposition, vacuum evaporation, printing or photoetching techniques.

50 The device shown in Figure 8a again includes a suspension layer 22 which can be any of the electrophoretic suspension layers described above. Suspension layer 22 includes at least one electrophoretic material suspended in a suspension medium and is enclosed in a housing 3 having two spaced opposed major housing walls 31 and 32, at least one of which is transparent; in the Figure, housing wall 31 is transparent and consists of a sheet of an insulating material,

for example, polyester, cellulose acetate, regenerated cellulose or polyethylene. 65

A first electrode 30 is not in this case applied to the housing wall 31, but is placed on the outer surface of the housing wall 31 so that it can be easily removed and yet is electrically coupled to the suspension layer 22. The second electrode is made of, for example, a metal plate and may constitute the other housing wall 32, as shown. 70

Alternatively, the other housing wall may be one which has a high electrical resistance. It is then possible to form the second electrode as a thin electrically conductive film attached to the inner surface of a high resistance housing wall 32 or it is also possible to use, as a second electrode, a metal plate on which a high resistance housing wall 32 is placed. When the housing wall 31 has a high electrical resistance, a higher D.C. voltage must be applied between the first and second electrodes. 75 80 85

If the electrode 30 has a given pattern a direct voltage applied between first electrode 30 and second electrode 32 will cause that pattern to be displayed on the surface of the housing wall 31 due to the electrophoretic migration of the electrophoretic material, even after removal of the first electrode 30. 90

If first electrode 30 is arranged as a pen-like electrode and moves freely on the surface of the housing wall 31, one can display any desired pattern on the surface of the housing wall 31, for example writing, by applying a direct voltage between the pen electrode 30 and second electrode 32, while moving the pen type electrode 30 manually to trace the said desired pattern. 95 100

An electric field can be applied across the suspension layer 22 by charging the surface of the housing wall 31, which should then have a high electrical resistance, with charged particles such as ions or electrons in a manner similar to that well known in the electrostatic recording art. 105 110

In order to erase the patterns produced on the display sheet by any of the means described above, a conductive roller with an applied electric voltage may be caused to roll on the top surface of the insulating sheet 31 or charged particles having a polarity such as to cause erasure may be directed on to the surface of insulating housing wall 31, so as to apply an electric field with reversed polarity across the suspension layer 22. 115 120

It is preferable, particularly when the walls are flexible, to insert between the housing walls 31 and 32 a colourless spacer such as a porous layer 39, as shown in Figure 8b, or a sheet 40 having many projections thereon, as shown in Figure 8c. This colourless spacer will ensure that the suspension layer 22 has a desired thickness by preventing the two 125

major housing walls 31 and 32 from touching each other, even when an electrode is pressed against the flexible housing wall 31, or when a flexible housing 3 containing an electrophoretic suspension layer in the liquid state is bent. The spacer can be made from any colourless sheet having pores or projections. One appropriate material is a screen textile formed of polyester or nylon fibre. The coloured porous layer 12 in Figure 2a must be substantially opaque so as to conceal the electrophoretic material, but colourless spacer 39 or 40 need not hide the electrophoretic material and is required only to act as a spacer between the housing walls.

The colourless spacer is inserted between the housing walls; at least one of the major surfaces of the spacer is preferably attached to the inner surface of a housing wall.

When a suspension layer includes a coloured porous layer, the coloured porous layer itself can in some cases act as a spacer between two major housing walls. In this case the provision of a colourless spacer is unnecessary.

In the apparatus illustrated in Figure 9, a housing 3 includes an insulating housing wall 31 and a transparent housing wall 5 having a transparent first electrode 9 applied thereto and connected to a source of electric power 10. An electrophoretic suspension layer 22 is enclosed in the housing 3, which forms the front face of the envelope 33 of a cathode ray tube.

Negative electron charges are deposited in a given pattern on the insulating housing wall 31 by a modulated electron beam emitted by an electron gun 34 and deflected by a deflecting apparatus 35, so that an electric field is applied across the electrophoretic suspension layer 22. A visible pattern will then be reproduced on the transparent housing wall 5 due to the electrophoretic migration of the electrophoretic material. The first electrode 9 acts as an anode. The second electrode is the electron gun 34 which acts as a cathode. The visible pattern can be erased by changing the velocity of the electron beam and making use of the secondary emission characteristics of the housing wall 31 to reverse the polarity of the applied charge.

The display device shown in Figure 9 can be modified in that the insulating housing wall 31 can be replaced by a well-known conductor mosaic faceplate consisting of a thin glass sheet having embedded therein hundreds of fine transversely extending wires. This wire-mosaic provides the electrical connection between the electron beam in the vacuum and the electrophoretic suspension layer which is outside the vacuum. The electron beam charges the wire-mosaic so as to apply an input electric field across the suspension layer 22.

In the arrangement shown in Figure 10 the suspension layer 22 may again be any of the suspension layers described above. The suspension layer 22 includes at least one electrophoretic material suspended in a suspension medium and is applied to a supporting member 36, such as paper, a metal plate or a plastic sheet. The supporting member 36 is placed on a second electrode 37. Since the suspension layer 22 is not enclosed in a housing, it must have a high viscosity, preferably it should be in a solid state at room temperature, and yet it must be such that it can be softened during application of a direct voltage by any suitable method, such as heating or the addition of a solvent.

A first electrode 30 having a predetermined pattern is placed in direct contact with the surface of the suspension layer 22. By closing a switch 11 a voltage source 10 is connected between electrodes 30 and 37 so that an electric field is produced between the first electrode 30 and the second electrode 37, so that the electrophoretic material will migrate electrophoretically when the suspension layer 22 is softened by heating or by addition of a solvent. Removal of electrode 30 leaves the charge pattern on the surface of the suspension layer 22. When the supporting member 36 is transparent a differently coloured pattern may be observed through it. A visible pattern can be reproduced permanently on the suspension layer 22 if this is returned to the solid state by cooling or by evaporating the solvent. When the supporting member 36 is conductive, it may also act as the second electrode 37.

The electrophoretic suspension layer used in carrying out the invention may be prepared by using any suitable known stable colloidal particles suspended in a suspension medium, such as colloidal graphite suspended in mineral oil, or colloidal silver particles suspended in water. In addition to colloidal particles, the electrophoretic material may comprise finely divided particles such as titanium dioxide, zinc oxide, carbon black, phthalocyanine blue, phthalocyanine green, hansa yellow or watchung red in stable suspension in a suspension medium such as kerosene, trichlorotrifluoroethane, isopropyl alcohol or olive oil. The particles of an electrophoretic material suspended in a suspension medium carry either a positive or negative charge, depending upon the properties of the electrophoretic material and of the suspension medium.

The electrophoretic suspension layer 2 or 6, 13 of Figure 1a or Figure 2a may include only one electrophoretic material having a positive or negative charge polarity when suspended in a suspension medium. The electrophoretic suspension layer 18 or 21 of Figure 3a or 4a must include at least two different electrophoretic materials suspended in a suspending medium. These electro-

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phoretic materials must differ in their optical reflectance properties and have either different charge polarities or different electrophoretic mobilities. Therefore, in preparing the electrophoretic suspension layer 18 or 21, at least one pair of electrophoretic materials having suitable optical reflective properties and electrophoretic properties must be suspended in a suspension medium.

The average particle sizes of the finely divided particles which will be suitable depends upon the stability and the covering power of the resultant electrophoretic suspension, and usually range from 0.1μ to 50μ .

It may be found advantageous to add to the suspension a suitable charge control agent, dispersion agent or stabilizing agent to provide a stable suspension layer in accordance with principles well known in colloidal chemistry. In order to control the charge properties of the particles suspended in a suspension medium, it may be advantageous to use particles coated with a resin which is not soluble in, or is only slightly soluble in, the suspension medium. When the coating resin is slightly soluble in the suspension medium, it can also act as a binder for the electrophoretic particles and thus as a fixing agent for a displayed image.

It is possible to use, as the suspension medium, any readily available and suitable liquid which is inert to the electrophoretic material, the housing and the electrodes. To produce a temporary display, a suspending medium which is in the liquid state at room temperature, e.g. from 0°C to 35°C may be used. To produce a permanent display, that is, a hard copy, a suspension medium which is in the solid state at room temperature and attains a liquid state at a temperature above room temperature, e.g. above 35°C , may then be used. Suspension media which are suitable for this purpose are, for example, waxes such as beeswax, vegetable wax, paraffin or synthetic wax.

When using such waxes, the device according to the present invention must be kept at a temperature higher than room temperature while the display or recording is being produced. After the device is subjected to a unidirectional electric field at the higher temperature to vary electrophoretically the spatial distribution of said electrophoretic material, it is cooled to room temperature to produce a persistent display. If it is desired to erase the persistent display, the device is subjected to an alternating or unidirectional uniform electric field at the higher temperature.

When the suspension medium consists of a thermosetting material which is in a liquid state at room temperature, a permanent display can be produced by heating the suspension medium after the electrophoretic

migration of the electrophoretic material has been effected.

Thermosetting materials which are suitable for use as suspension media are, for example, drying oils such as linseed oil, soya oil or tung oil. When the liquid suspension medium includes a binder such as polystyrol, vinyl acetate resin or linseed oil which fixes the electrophoretic material in finely divided powder form, a hard copy having a permanently visible image reproduced thereon can be obtained by evaporating or exhausting the residual suspension medium. The evaporation or exhaustion of the suspension medium can be achieved by, for example, evacuating the housing containing electrophoretic material in a suspension medium through an outlet formed, for example, in the housing wall.

A housing for use in a device according to the present invention can be prepared by using any material which is inert to the suspension medium and to the electrophoretic material. For example, a plastics sheet having a major central portion cut out can be used for the frame 38 of the housing 3 as shown in Figure 1a. One of the two opposed major housing walls can be provided, for example, by securing a metal plate to the frame by means of an adhesive. The metal plate acts as one of the aforesaid two electrodes. The other of the two opposed major housing walls can be provided, for example, by securing a transparent glass plate having a transparent conductive thin film such as tin oxide or cuprous iodide to the frame by means of an adhesive in such a way that the transparent conductive thin film is brought into contact with the electrophoretic suspension layer.

An electrophoretic material suspended in a suspension medium can be poured into a housing having only one major housing wall. After that, the other major housing wall can be attached to the frame.

Another method is to pour the electrophoretic material suspended in a suspension medium into the housing through an inlet aperture formed, for example, in the housing wall. The inlet is closed after the housing is filled with the electrophoretic suspension.

One can use any appropriate apparatus for applying to the electrodes the voltage which is required to produce an electric field across the suspension layer. For example, a pulse generator, a battery or any other direct voltage source can be used. In order to erase the displayed image, an alternating voltage source can also be used.

It has been discovered that when at least one of the first electrode and second electrode is coated with an insulating layer which is in contact with the suspension layer, the device according to the present invention has

an improved operating life. The insulating layer prevents the breakdown of the insulating properties of the suspension layer even when a high voltage is applied thereto and makes it easy to remove the electrophoretic material from the electrode surface in order to form a new image by subjecting the device to a unidirectional electric field of reversed polarity on to an alternating field.

In the arrangement shown in Figure 11 a first electrode 8 is coated with an insulating layer 43 which is not soluble in the suspending medium. Instead of the first electrode 8, the second electrode 9 or both the first and second electrodes 8 and 9 can be coated with insulating layers. The insulating layer 43 is prepared by coating the electrode with, for example, vinyl acetate resin, polystyrol or gelatin. A transparent insulating layer is thus applied to a transparent electrode attached to a transparent housing wall. The thickness of the insulating layer 43 depends on the electrical resistance which said insulating layer and the electrophoretic suspension layer 22 are required to have. For operation at a low voltage it is preferable that the insulating layer 43 shall have an electrical resistance no higher than that of the suspension layer 22.

In Figure 12a is shown an arrangement in which the suspension layer 22 has a plurality of spacers extending transversely thereof and consists of many small spaces filled with the suspension. A sheet 41 with multitudinous holes 42 therein, as shown in Figure 13, can alternatively be used to divide the suspension layer 22 into separate suspension units.

The holes 42 can have any suitable shape, such as square, as shown in Figure 13, circular, rectangular, hexagonal, and so on. The holes 42 can be regular or irregular in shape, dimension and order. The dimensions of the holes should be selected according to the purpose of the display or the nature of the suspension, but they must be at least greater than the dimensions of the particles of electrophoretic material in the suspension.

The advantages of dividing the suspension layer into a plurality of suspension units are as follows: a uniform display can be produced because the flow of the suspension is restricted to the interior of each space. The plurality of suspension units can have optical reflectance properties which differ from each other. It is possible for the plurality of suspension units to have at least two colours. The plurality of suspension units are preferably inserted between two electrodes, one of which has a plurality of electrode portions (E_1, E_2, E_3, \dots), for example, in the form of dots which are in contact with the plurality of suspension layer units, respectively, and the other of which is transparent and covers the whole of the transparent housing wall 4, as shown in Figure 12b. The device as

shown in Figure 12b can produce a colour image by applying a direct voltage between the common electrode 8 and selected ones of the electrode portions E_1, E_2, \dots

The best way to provide electrodes for the plurality of suspension units is to provide a first electrode consisting of a plurality of electrode strips disposed parallel to each other and a second electrode consisting of a plurality of electrode strips which are disposed orthogonal to said first electrodes, similar to the arrangement shown in Figure 7, in such a way that each of the intersection points of said first electrodes and said second electrodes is operatively associated with one of the plurality of suspension units. Each of the intersection points forms a picture element in association with a respective suspension unit which may be coloured red, as at 22R, green as at 22G, or blue, as shown at 22B in Figure 12c. The application of an appropriate voltage to desired picture elements will reproduce a coloured image on the image display panel.

A display panel for a colour image can be prepared by using only one kind of suspension capable of changing in colour in shades of grey between black and white. This is accomplished by making the areas of the transparent housing wall corresponding to each picture element in a display panel, as shown in Figure 7, selectively coloured so that it acts as a colour filter for red, green or blue. However, a display panel having at least three kinds of suspensions, i.e. red, green and blue, and produce a better colour image, especially with respect to brightness in the highlights, than can a panel with mosaic colour filters on the transparent housing wall.

In a character display panel, as described in Figure 6, the suspension corresponding to one of the electrode portions can consist of one or more suspension units.

The amount of electrophoretic material in the suspension medium or the thickness of the electrophoretic suspension layer is selected, in accordance with the covering power or the electrophoretic properties of the electrophoretic material, the range of colour change required in the device, the available voltage source and so on. The high value of the covering power of pigment particles available commercially is helpful in preparing the suspension. For example, the values of the covering powers of titanium dioxide particles and acetylene black particles are, respectively, about 130 cm^2 and $25,400 \text{ cm}^2$, per gm in the conventional suspension liquids such as linseed oil. Therefore, at least 1 gm of titanium dioxide particles and at least 5 mg acetylene black particles respectively are required to change the colour of a display panel having an area of 130 cm^2 from effectively black to effectively white. When the thickness of suspension layer is to be 1 mm,

the amount of particles of each pigment must be introduced into 13 ml of the suspension medium.

Since the display device of the present invention is the reflective type, the suspension layer must be opaque in order to produce a large colour change. The thicker the suspension layer, the higher the applied voltage which is usually required. The thinner the suspension layer, the denser the concentration of the electrophoretic material must be to produce a large colour change. The thickness of the suspension layer is usually from a few microns to few mm.

The invention will now be still further described in relation to specific examples.

EXAMPLE 1

A mixture of particles as described in Table 1 was combined with 100 ml of isopropyl alcohol. The mixture in the isopropyl alcohol was well mixed to produce a grey paste having white and black particles suspended in isopropyl alcohol. In this grey paste, the titanium dioxide particles are positively charged and the black toner particles are negatively charged. A housing as shown in Figure 1 was filled with the grey paste so as to form an electrophoretic suspension layer. The housing had two opposite major housing walls with a size of 60×60 mm. The two major housing walls were provided with transparent electrodes, each of which was a thin film of tin oxide applied to a transparent glass plate. This electrically conductive glass is called EC glass in the following examples. A side frame was prepared from 25 μ thick polyester film in a manner similar to that described above. The thickness of the electrophoretic suspension layer was thus 25 μ . This electrophoretic suspension layer was almost opaque and grey when viewed through either of the transparent electrodes under the light of an incandescent lamp.

TABLE 1

Titanium dioxide:

10g (a brand R-680 commercially available from the Ishihara Industrial Company in Japan, or rutile type having a particle size of 0.15—0.3 μ .)

Black toner particles:

20g (Type-10 manufactured for electrophotography by the Rank Xerox Company in England).

When a direct voltage of 25V was applied between the two electrodes, the suspension layer changed in colour, becoming black at the anode and white at the cathode. The black colour at the anode or the white colour at the cathode remained stable even after the applied voltage was cut off.

The colour on one side could be changed from black or white respectively to white or to black by reversing the polarity of the applied voltage. The application of an alternating voltage of 25V at 60 Hz between the two electrodes changed the colour from the white at the cathode or the black at the anode to grey at both electrodes, and it remained in this original condition.

When the applied alternating voltage had a frequency below about 20 Hz, the brightness of the suspension layer was altered periodically from the white through grey to black and vice versa in accordance with the frequency of the applied voltage. The application of a direct voltage below 25V changed the colour gradually and continuously from grey to white at the cathode and to black at the anode. A desired grey colour between the white and the black remained in a stable condition after the voltage is switched off at the moment when the desired colour appeared on the panel.

A rapid change in the brightness of the suspension layer could be obtained by applying a direct voltage above 25V with a definite pulse width. The colour of the panel was simply and easily changed so that the panel was useful for conveying information.

EXAMPLE 2

Fifteen grams of finely divided titanium dioxide particles (as in Table 1) and fifteen grams of black toner particles (as in Table 1) were added to 200 ml of olive oil.

The mixture is well mixed in a ball mill to produce a grey paste. In this grey paste, the titanium dioxide particles were positively charged and the black toner particles were negatively charged. A housing similar to that of Example 1 was filled with the grey paste so as to produce a cell having an electrophoretic suspension layer as shown in Figure 3. The thickness of the electrophoretic suspension layer was 100 μ .

The side faces of the cell were made liquid-tight by an adhesive agent, for example, the epoxy resin adhesive known under the Trade Mark "Araldite", while each electrode was left partially exposed to allow for connection of leads.

The application of a direct voltage of 250V between the electrodes for about 1 second changed the colour of the suspension layer at each electrode; a change in colour from grey to white being observed at the cathode and from grey to black at the anode. A current meter with a recording apparatus connected between the voltage source and the cell indicated that the average current flowing during electrophoresis of the particles was about 4×10^{-5} amperes per cm² of the cell. This means that the display apparatus had a rather high electrical efficiency. By the application of a direct voltage below 250V,

the brightness of the suspension layer can be altered slowly and it remains stable at the desired level.

EXAMPLE 3

- 5 Ten grams of Heliogen blue LBGT particles, which are phthalocyanine blue supplied by the BASF Company in Germany, were added to 100 ml of olive oil and mixed well in a ball mill so as to produce a blue paste.
- 10 Fifteen grams of hansa yellow G particles, which are an azo type organic pigment supplied by the Kanto Chemical Company in Japan, were added to 100 ml of olive oil and well mixed in a ball mill so as to produce a yellow paste. Equal amounts of the two pastes were well mixed to produce a green paste.

- The green paste was placed between an aluminium plate and a conductive glass electrode so as to produce an electrophoretic suspension layer with a thickness of 25μ . When a direct voltage of 100V was applied between the glass electrode as an anode and the aluminium plate, the colour of the suspension layer as viewed through the glass electrode turned from green to yellow under a white light. The colour of the suspension layer was changed to blue by reversing the polarity of the applied voltage.

- 30 Control of the strength, of the length of time of application or of the polarity of the applied voltage made it possible to change the colour of said suspension layer continuously from the colour of the yellow particles through that of a mixture of the yellow particles and the blue particles, to that of the blue particles and vice versa. This was because the suspension layer adjacent to the glass electrode includes a mixture of blue and yellow particles in various ratios.

- Such a cell is thus useful as a colour changeable panel capable of altering the colour of the suspension layer continuously throughout the colour range of the colours blue, green and yellow.

EXAMPLE 4

- Four grams of hansa yellow G particles (as in Example 3) were added to 50 ml of olive oil and well mixed in a ball mill to produce a yellow paste.

- 50 Eight grams of ultramarine particles supplied by the Daiichi Kasei Industrial Company in Japan were added to 50 ml of olive oil and well mixed in a ball mill to produce a blue paste.

- 55 Equal amounts of the pastes were well mixed to produce a green paste. A housing which employed, as opposed major housing walls, two flexible transparent electrodes made from a sheet of cellulose diacetate (CDA) and having a transparent conductive layer of cuprous iodide (Cu_2I_2) applied to each wall was filled with the green paste. A

sheet of Tectron screen (#1350 a screen woven of polyester fibres supplied by the Teijin Company in Japan) was inserted between said two flexible transparent electrodes in the manner shown in Figure 8b.

When a direct voltage of 200V is applied between the two flexible transparent electrodes, the anode became yellow and the cathode became dark blue-green. A reversal of the polarity of the applied voltage caused the colours of the two electrodes to change from yellow to blue-green and from blue-green to yellow, respectively.

Hansa yellow G particles are negatively charged, but ultramarine particles do not have any great electrophoretic activity in olive oil. In this suspension layer, the yellow particles capable of moving electrophoretically are thus suspended in a blue-coloured suspension medium consisting of olive oil coloured by ultramarine particles.

Such a cell was useful as a flexible sheet capable of changing colour throughout a colour range from yellow through green and blue-green, depending on the strength, length of time of application, and polarity of the applied voltage.

EXAMPLE 5

A mixture of particles described in Table 2 was combined with 50 ml of isopropyl alcohol. This mixture in isopropyl alcohol was well mixed by an ultrasonic vibrator to produce a yellow-green suspension.

TABLE 2

Cadmium sulphide particles:
10g (commercially available from the Sakai Chemical Industry Company in Japan).

Patent blue A particles:
2g (commercially available from the Kanto Chemical Industry Company in Japan).

A housing was filled with the suspension so as to form an electrophoretic suspension layer, as shown in Figure 1. The opposed major housing walls of the housing were made of conductive glass electrodes. The side frame was made of a polyester film. The thickness of the electrophoretic suspension layer was 25μ .

When a direct voltage of 15V was applied between the electrodes, the suspension layer changed in colour. It became yellow at the cathode and green at the anode. The colour on the respective sides could be changed from yellow or green or to green or to yellow respectively by reversing the polarity of the applied voltage.

EXAMPLE 6

Thirty-five grams of a cobalt naphthenate, metal content 8%, by weight (supplied by

the Kanto Chemical Company in Japan), was dissolved in 100 ml of trichlorotrifluoroethane to produce a red-brownish solution. Twenty grams of titanium dioxide particles (as in Table 1) were added to the solution and well mixed to produce a faint pink paste. In this paste, the titanium dioxide particles were positively charged. A housing was filled with the paste so as to form an electrophoretic suspension layer.

The major housing walls of the housing were made of conductive glass to form electrodes. The thickness of the suspension layer was 50μ . When a direct voltage of 50V was applied between the two electrodes, the suspension layer changed in colour, becoming white at the cathode and brown at the anode.

Control of the strength, the length of time of application and the polarity of the applied voltage changed the intensity of the brown colour at one side of the panel continuously. The established colour remained stable even after removal of the applied voltage.

In the suspension as described above, the cobalt naphthenate functioned as a colouring agent for the transparent suspension medium consisting of trichlorotrifluoroethane, as a charge control agent for stabilising the positive charge of the titanium dioxide particles, and as a dispersion agent for stabilizing the suspension.

EXAMPLE 7

Ten grams of titanium dioxide particles (as in Table 1) were added to 100 ml of olive oil and well mixed in a ball mill so as to produce a white paste.

A housing was provided which was similar in construction to that of Figure 2a. The two opposed major housing walls were formed respectively of an aluminium plate and of a conductive glass electrode which acted as first and second electrodes, respectively. The glass electrode had an insulating layer of vinylacetate resin having a thickness of about 7μ applied over the SnO_2 coating. A thick dark blue cloth was inserted as a coloured porous layer between the first and second electrode. This thick dark blue cloth had a thickness of about 100μ . A suitable thick dark blue cloth which can be used is "Bemberg" which is the trade name of cloth manufactured at the Asahi Kasei in Japan. A sheet of Tetron screen #1000 (supplied by the Teijin Company in Japan) was placed between the aluminium plate and thick dark blue cloth.

A sheet of another Tetron screen #1350 (supplied by the Teijin Company) was placed between the insulating layer on the glass electrode and the thick dark blue cloth. The housing was filled with the above described white paste. The thick dark blue cloth and Tetron screen had the white paste impregnated therein. The panel had a faint blue

colour at the glass electrode before application of a direct voltage.

When a direct voltage of 400V was applied between the glass electrode as cathode and the aluminium plate as anode, the panel had a white colour at the glass electrode. This is because white titanium dioxide particles in the paste move electrophoretically to the glass electrode and hide the thick dark blue cloth from sight at the glass electrode.

The colour of the panel at the glass electrode changed from white to blue upon reversal of the polarity of the applied voltage.

EXAMPLE 8

An SnO_2 layer on a conductive glass electrode was coated with a photoresist solution, for example KPR, available commercially from the Kodak Company in U.S.A., and is etched by a well known photoetching technique so as to form electrode portions as shown in Figure 6c. For convenience, the glass electrode having these segmental electrodes formed thereon is hereinafter called a transparent electrode. A housing was prepared by using this transparent electrode as one electrode and an aluminium plate as another electrode in a way similar to that described in the foregoing description. The inner surface of the aluminium electrode was coated with an insulating layer of vinyl acetate resin having a thickness of about 8μ .

The housing was filled with a grey paste exactly the same as that of Example 2, which formed a suspension layer having a thickness of 25μ . The electrode portions were connected, through switches, to one terminal of a direct voltage source. The glass electrode had a grey colour before a D.C. voltage was applied.

The other terminal of the direct voltage source was connected to the aluminium electrode. The application of a direct voltage of 200V between the aluminium electrode and selected electrode portions produced a desired numerical character on the glass electrode. For example, selection of electrode portions $S_1, S_2, S_3, S_4, S_5, S_6$ (references as in Figure 6) produced "0"; the selection of electrode portions S_1-S_6 produced "8"; the selection of electrode portions S_1 and S_2 produced "1". When the electrode portions were charged positively, the numerical character which was produced appeared black; the opposite charge produced a white numerical character.

WHAT WE CLAIM IS:—

1. An image display or recording device comprising an electrophoretic suspension layer comprising at least one material which exhibits electrophoresis even in the absence of illumination suspended in a suspension medium, first and second bounding mem-

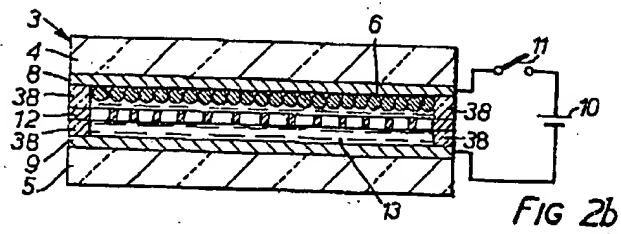
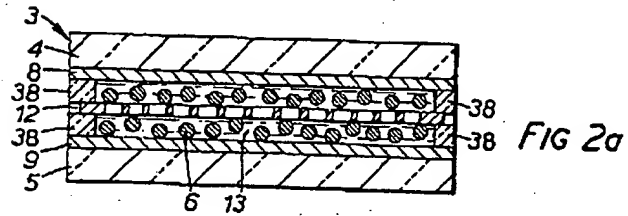
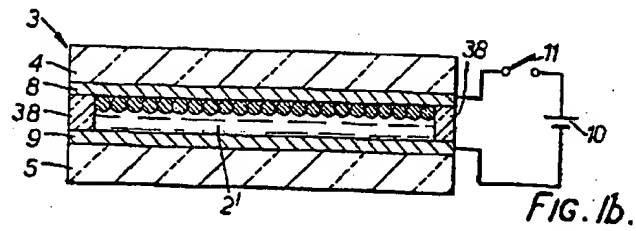
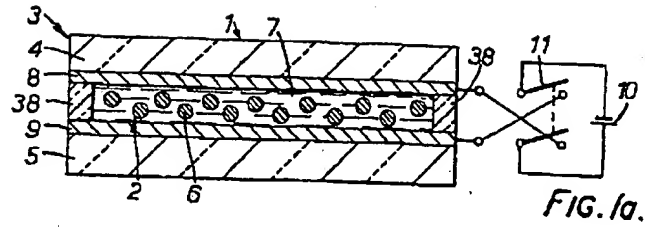
- bers immediately adjacent the main surfaces of said layer and comprising first and second electrode means respectively, at least one of the members being transparent and the first and second electrode means being arranged to produce in said layer an electric field such as to cause a said electrophoretic material to be deposited upon one of the bounding members.
- 5 2. A device in accordance with claim 1 wherein one at least of said electrodes means comprises an electrode having the form of a symbol to be displayed.
- 10 3. A device in accordance with claim 1 wherein one at least of said electrode means comprises a plurality of discrete electrode portions arranged for selective connection to a voltage source.
- 15 4. A device in accordance with claim 3 wherein each of said electrode means includes an array of parallel strips, the strips of each array being disposed orthogonally to those of the other.
- 20 5. A device in accordance with claim 3 wherein one of said electrode means comprises a plurality of electrode strips arranged for selective excitation to display a plurality of distinct characters.
- 25 6. A device in accordance with claim 1 wherein one of said electrode means includes a source of charged particles arranged to project said charged particles upon a wall of an enclosure containing said electrophoretic layer whereby to vary the charge distribution thereon.
- 30 7. A device in accordance with claim 6 wherein said enclosure wall is a conductor mosaic.
- 35 8. A device in accordance with claim 1 wherein one of said electrode means includes a pen-like electrode movable over a surface of said layer or of a container therefor.
- 40 9. A device in accordance with any one of claims 1 to 3 wherein means are provided whereby said electrode means is movable relative to the suspension layer so that it may be applied temporarily to a surface of said electrophoretic suspension layer.
- 45 10. A device in accordance with any one of claims 1 to 3 or 5 to 9 wherein one of said electrode means includes a first electrode extending over the whole of one surface of said layer.
- 50 11. A device in accordance with claim 1 wherein each of said electrode means includes first and second electrodes extending over the whole of a respective surface of said layers.
- 55 12. A device in accordance with any one of claims 1 to 3 or 5 to 11 wherein either of said first and second electrode means constitutes a wall of a container for said layer.
- 60 13. A device in accordance with any one of the preceding claims wherein at least one of first and second electrode means is covered by a layer of insulating material.
- 65 14. A device in accordance with any one of the preceding claims wherein said electrophoretic layer includes at least two said electrophoretic substances of differing charge polarities and optical reflectances.
- 70 15. A device in accordance with any one of claims 1 to 13 wherein said electrophoretic layer includes at least two electrophoretic substances of differing electrophoretic mobilities and optical reflectances.
- 75 16. A device in accordance with any one of the preceding claims wherein said suspension medium is coloured.
- 80 17. A device in accordance with any one of claims 1 to 16 wherein a layer of coloured porous material is immersed in said suspension medium.
- 85 18. A device in accordance with any one of claims 1 to 16 wherein said layer is held in a container and in which a plurality of spacer means are provided to ensure a predetermined minimum separation of the container walls.
- 90 19. A device in accordance with any one of the preceding claims wherein said suspension layer further includes a binder for said electrophoretic particles, said binder being at least slightly soluble in said suspension medium.
- 95 20. A device in accordance with any one of claims 1 to 18 wherein said suspension medium is a hardenable material.
- 100 21. A device in accordance with claim 20 wherein said suspension medium is heat hardenable.
- 105 22. A device in accordance with claim 20 wherein said suspension medium is heat softenable.
- 110 23. A device as claimed in claim 20 wherein said suspension medium is softenable by the addition of a solvent.
- 115 24. A device in accordance with any one of the preceding claims together with means for varying at least one of the intensity, the time of application or the polarity of the electric field produced in said layer.
25. A device in accordance with claim 6 or claim 7 wherein an enclosure containing said layer forms one wall of the envelope

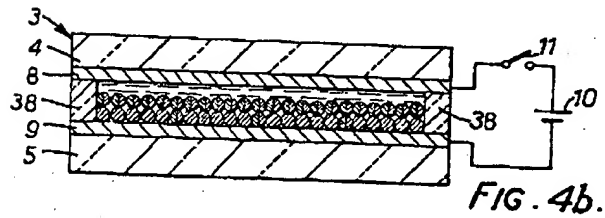
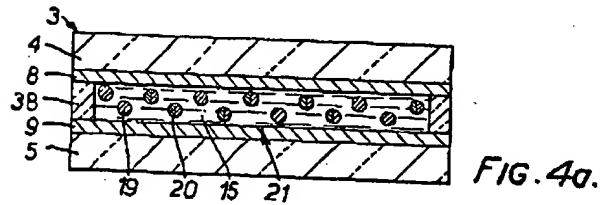
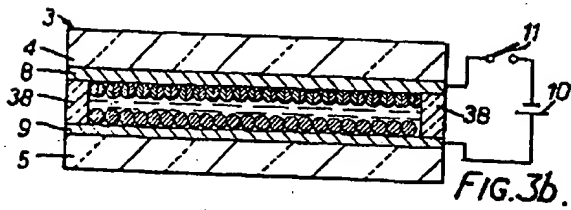
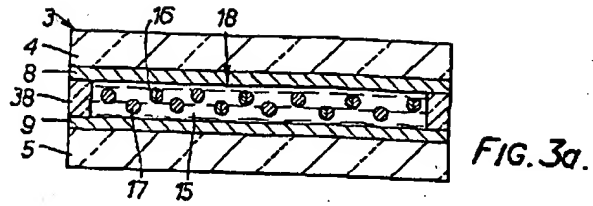
of a cathode ray tube comprising said source of charged particles.

26. An image display device substantially as described with reference to any of the
5 several Figures of the accompanying drawings.

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COMPLETE SPECIFICATION

5 SHEETS

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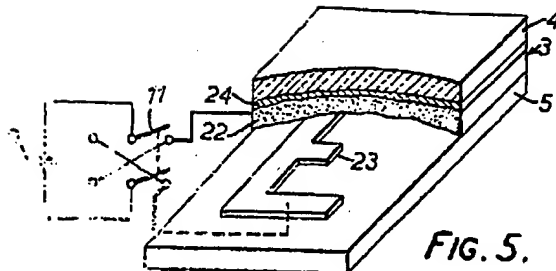


FIG. 5.

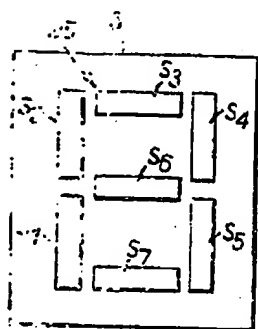


FIG. 6a.

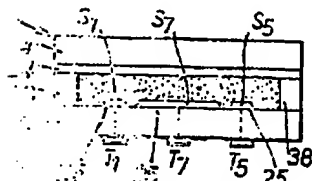


FIG. 6b.

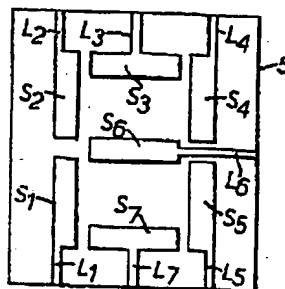


FIG. 6c.

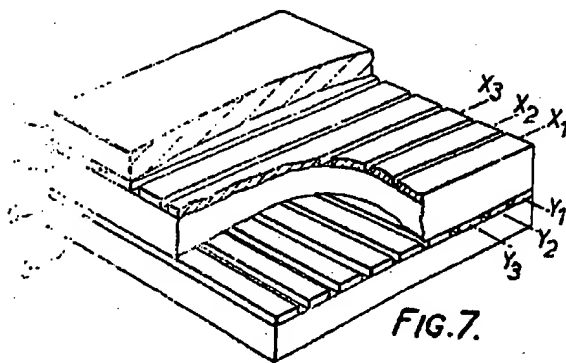
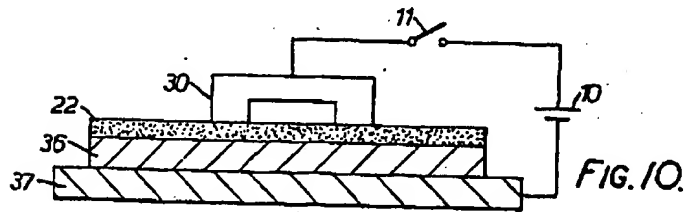
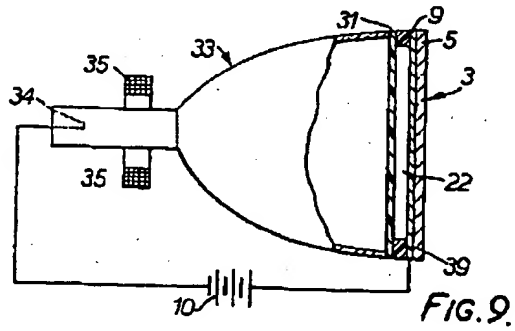
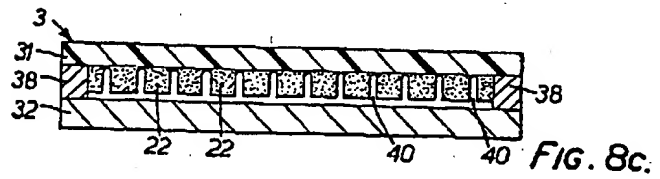
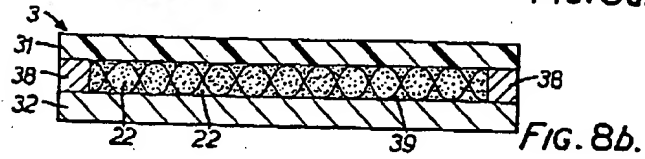
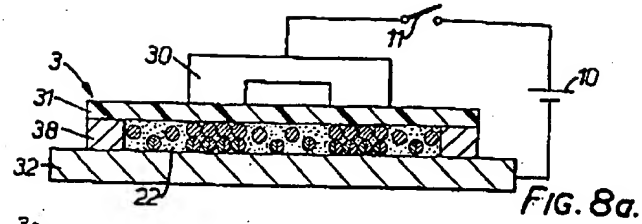


FIG. 7.



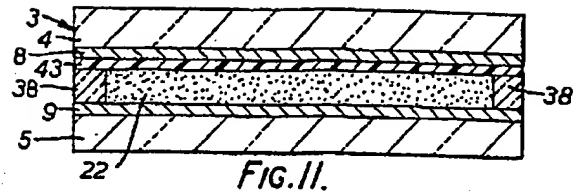


FIG. 11.

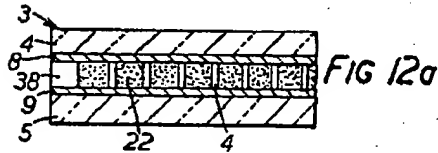


FIG. 12a

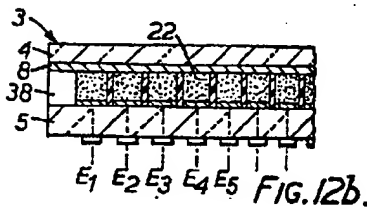


FIG. 12b.

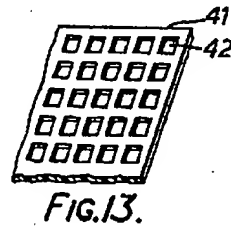


FIG. 13.

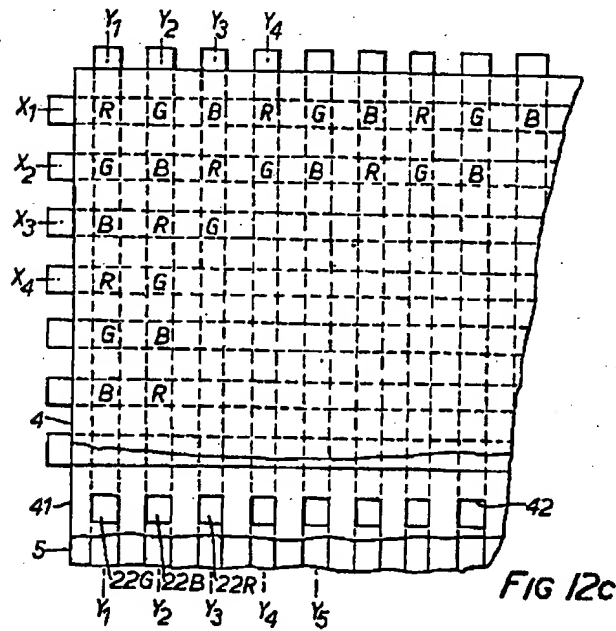


FIG. 12c